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A Study on the Location of Emergency Logistics Distribution Center with Multi-Objective Planning under Emergency Situation-Beijing as an Example

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ABSTRACT

As the modernization of cities continues to advance, the connection between and within cities is getting closer and closer. While bringing convenience to people, it also brings new challenges for emergency response to various disasters and incidents. Cities have become the focus of national and social disaster prevention and mitigation. The primary function of the emergency logistics supply system is to provide timely and sufficient relief materials for the affected areas, and the emergency logistics distribution center plays a very important role in the whole emergency process as the node facility at the end of the emergency logistics supply chain. China's emergency logistics is still in its initial stage and lags behind compared with developed countries. There are problems such as lack of emergency logistics infrastructure, incomplete information for emergency decision-making and lack of scientific design of emergency supply chain. There is no official emergency logistics distribution center in Beijing yet, which leads to a long time shortage of material supply during the New Crown epidemic. This paper selects a site for an emergency logistics distribution center in Beijing through a multi-objective planning model, hoping to improve the state of emergency logistics in Beijing by establishing an emergency logistics distribution center, which is very important in the emergency logistics chain.

KEYWORDS: *Multi-objective planning; Emergency logistics; Site selection*

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1. INTRODUCTION

In recent years, there has been a rising trend of various disasters and accidents in cities around the world, with earthquakes, snowstorms, floods, sudden outbreaks of epidemics and other kinds of emergencies occurring constantly, bringing serious damage to cities. In Beijing, for example, from the big explosion in Chaoyang District in 2011 to the major fire in Daxing District in 2017 to the forest fire in Yanqing in 2020, although the frequency of major disasters is not considered frequent, it can be seen from the big explosion in Tianjin to the new crown epidemic in recent years that any major domestic disaster will have an impact on the life of the city.

This paper focuses on the site selection of emergency logistics distribution centers from the perspective of Beijing under the premise of major emergencies. The main purpose is to construct a more scientific site selection model, fully consider the influencing factors of emergency logistics distribution center site selection, effectively provide theoretical reference for the current emergency logistics distribution center, improve the operational efficiency of the emergency logistics system in Beijing, improve the response speed of Beijing to disasters and accidents, and reduce the loss of life and property. The analysis and research on the site selection of emergency logistics distribution center in Beijing can not only improve the scientific and advanced emergency management in Beijing, but also provide reference for the construction of emergency logistics system in other cities in China.

2. Literature Review

The emergency logistics distribution center site selection problem studied in this paper belongs to the emergency logistics site selection problem, for which many experts and scholars at home and abroad have conducted research based on different objectives and perspectives.

In foreign countries, foreign scholars Adel A, White [1] constructed an aggregate coverage model to solve the minimum number of emergency service facilities; D. R. Shier [2] proposed an absolute center model for single facility siting with the objective of minimizing the distance between facility points to network nodes; Albert et al. used time as the objective of emergency siting, and made a more Albert et al. In the actual situation, the single coverage model cannot guarantee that the service facilities can provide timely and effective services in case of an accident at each location, and in response to this problem, Matsutomi T. et al. used fuzzy mathematical methods to study the multi-objective emergency facility siting problem; Suleyman believed that the nature of the emergency logistics siting decision problem is a multi-objective optimization problem, and it is necessary to solve the problem of compromising the use of resources in siting. Hogan, Reveille studied the emergency response problem of other service facilities and proposed two alternate coverage models, BACOP1 and BACOP2. Jia HZ, Dessouky M constructed a 0-1 linear programming model for siting medical service facilities and used heuristics such as genetic algorithm and Lagrange relaxation algorithm algorithms for solving.

In China, Liu Chunlin et al. carried out site selection optimization with the objectives of minimum number of rescue points and earliest emergency start time. Yi-Cheng Zhang [3] et al. constructed a multi-objective emergency service facility siting model considering the reliability of the emergency system. Ling Zhang et al. performed grouping and scenario analysis of disaster areas to determine the demand for emergency supplies, and then constructed a multi-objective planning site selection model to solve the site selection problem of multiple demand and emergency points. In his doctoral dissertation, Li Guoqi constructed a single-objective model for siting emergency logistics facilities under the premise of satisfying the demand for emergency supplies and with the objective of minimizing operation costs.

In summary, although scholars at home and abroad have studied different aspects of emergency logistics facility site selection, it can be seen that the multi-objective planning model is very scientific, therefore, this paper selects the multi-objective planning model to study the site selection of emergency logistics distribution center.

3. Model construction

Different types of emergency logistics facilities have different characteristics, and this paper takes emergency logistics distribution center as the research object, whose influencing factors are mainly micro factors, and the constraints in site selection are also more micro constraints. In order to facilitate the research, the influencing factors and constraints to be considered in this paper are selected as microscopic influencing factors and microscopic constraints.

The site selection of emergency logistics has multi-attribute characteristics, therefore, its site selection process involves multiple objectives. Firstly, unlike general logistics service facilities, the construction and operation and maintenance costs of emergency logistics distribution centers are high, and the logistics costs should be considered in the site selection process; secondly, in order to deliver emergency materials to the disaster area at the first time after a disaster accident, the transportation distance between the distribution center and the demand point must be considered so that the total distance is minimized; next, because major disaster accidents occur with uncertain locations and therefore should focus on the efficiency and fairness of coverage, so that the maximum distance from the emergency logistics distribution center to the emergency demand point is minimized. Emergency logistics site selection involves multiple objectives, and the multi-objective planning method can effectively solve this kind of site selection problem, which can consider multiple objectives for decision making and fully reflect the fairness and efficiency of emergency logistics.

In summary, this paper considers the micro aspect and establishes a multi-objective mathematical model to select a specific emergency logistics distribution center address. With the microscopic site selection objectives of maximum coverage efficiency, minimum total distance and minimum total cost and expense, a three-objective mathematical planning model is established, and an algorithm is designed to solve it according to the characteristics of the model and the actual situation of Beijing.

3.1. Analysis of influencing factors of model design

Using the hook-drawing method, 20 faculty and students in logistics were asked to conduct statistics on the research content of micro-influencing factors for emergency logistics site selection, as shown in Table 1.

Table 1 Statistical table of micro-influencing factors of emergency logistics site selection

No.	Teacher	Cost	Total distance	Coverage efficiency	Time	Carrying capacity
1	Teacher 1	√	√			
2	Teacher 2	√			√	
3	Teacher 3			√	√	
4	Teacher 4	√	√	√		
5	Teacher 5			√		√
6	Teacher 6					
7	Teacher 7	√				√
8	Teacher 8			√		√
9	Teacher 9			√		
10	Teacher 10	√				
11	Teacher 11			√		
12	Teacher 12		√			
13	Teacher 13			√		
14	Teacher 14	√	√			
15	Teacher 15	√	√			
16	Stusent 1	√				√
17	Stusent 2		√	√		
18	Stusent 3	√				
19	Stusent 4	√			√	
20	Stusent 5	√		√		

3.2. Model Building

3.2.1. Site Selection Objectives

Based on the above, it can be concluded that the model in this paper has three objectives:

Total distance minimization: The total distance between the emergency distribution center and each demand point is minimized.; Maximum coverage efficiency: the emergency distribution center makes the coverage of the demand area under the condition that there is a limit to the number of the maximum total weight; Lowest total system cost: The cost of emergency logistics distribution center mainly includes construction cost, operation and maintenance cost and distribution and transportation cost.

3.2.2. Site Selection Objectives

In order to facilitate the construction of mathematical models and simplify data calculation, the following assumptions are made in this paper:

A. The urban emergency distribution centers and the demand for emergency supplies are distributed in a point-like manner;
B. The urban emergency distribution centers and the demand points for emergency materials can be connected by some transportation mode;
C. The number of emergency logistics distribution centers is limited to p due to financial constraints;
D. The constructed emergency logistics distribution center stores only one kind of materials;
E. There is no capacity limitation for the emergency logistics distribution center;
F. The reachable distance between the site of the emergency logistics distribution center and the demand point is the straight line distance between the two points;
G. The transport distance, transport quantity and transport cost are proportional to each other;
H. The distribution center must be selected among the given emergency distribution center site points to establish the distribution center.

3.2.3. Parameter Setting

j is the emergency logistics distribution center site, then $j\{1,2,3,\cdots,n\}$ is the set of n alternative sites in the emergency logistics system; i is the demand point of emergency materials, then $i\{1,2,3,\cdots,m\}$ is the set of m emergency demand points in the emergency logistics system; each demand area has different probability of

disaster occurrence, the greater the risk of an area, the greater the demand for emergency materials. In the model, the demand for emergency materials in the demand area can be evaluated by the population and GDP, and the risk level can be evaluated by the historical average probability of major disasters in the demand area. The importance of the demand area can be assessed by the product of its value and the probability of occurrence of emergencies.

ω_i is the importance of the ith demand area;

r_i is the historical average probability of a major disaster incident in the ith demand area;

e_i is the gross economic product of the i-th demand region;

m_i is the total population of the i-th demand area

$\omega_i = r_i \times (e_i + m_i)$ indicates the importance of the region；

c_{ij} is the transportation cost per unit distance per unit material from the jth alternative point to the i-th demand point;

f_j is the cost of land and construction costs to establish the distribution center at address j;

C_j is the operating cost of establishing a distribution center at the jth address;

D_i is the demand for emergency supplies at the I th demand point;

d_{ij} is the distance from the j th alternative point to the I th demand point;

p is the restricted quantity of the emergency reserve pool;

x_{ij} is the quantity of emergency supplies transported from the jth alternative point to the i-th demand point;

N_i is the set of all alternative emergency material distribution centers covering demand point i, where $N_i = \{j|d_{ij} \le S\}$；

y_j is whether the jth alternative emergency distribution center is selected or not;

a_i is the case whether demand point i is covered or not.

Now, from the alternative addresses, we determine an address to establish an emergency logistics distribution center that minimizes the total distance, maximizes the coverage value and minimizes the total cost of the system under the condition that the demand for emergency supplies is met.

3.2.4. Model Building

Based on the above siting objectives, model assumptions, and parameter settings, the mathematical model constructed in this paper is as follows:

$$\min\ z_1 = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}\, y_j \qquad (1)$$

$$\min\ z_2 = \sum_{i-1}^{m}\sum_{j=1}^{n} c_{ij}\, d_{ij}\, x_{ij} + \sum_{j=1}^{n}(f_j + C_j)\ y_j \qquad (2)$$

$$\min\ z_3 = \sum_{i=1}^{m} \omega_i\, a_i \qquad (3)$$

$$S.T. \sum_{j=1}^{n} y_j = p\ (j = 1,2,3\cdots,\ n) \qquad (4)$$

$$\sum_{j=1}^{n} x_{ij} \ge D_i (i = 1,2,3,\cdots,m;\ j = 1,2,3,\cdots,n) \qquad (5)$$

$$y_j \in \{0,1\} (j = 1,2,3,\cdots,n) \qquad (6)$$

$$x_{ij} \ge 0 (i = 1,2,3,\cdots,m;\ j = 1,2,3,\cdots,n) \qquad (7)$$

$$a_i \in \{0,1\}, (i = 1,2,3,\cdots m) \qquad (8)$$

$$a_i \le \sum_{i \in Ni} y_j, (i = 1,2,3,\cdots,m) \qquad (9)$$

In the above model the objective function (1) indicates that the total distance from the selected emergency logistics distribution center location to the emergency demand point is minimized; objective function (2) indicates the lowest total system cost including transportation cost and other related costs; Objective function (3) indicates the maximum total demand that can be covered with a limited number of distribution centers; Constraint (4) indicates that the choice of the number of emergency reserve depots is limited to Constraint (5) indicates that the emergency supplies delivered can meet the demand at each demand point; Constraint (6) indicates that the site selection decision is a 0-1 constraint, i.e., to establish or not to establish; constraint (7) indicates that the quantity of delivered supplies is a non-zero constraint; constraint (8) indicates that the siting decision is a 0-1 constraint, i.e., the demand point is covered or not covered; Constraint (9) indicates that the demand point can be covered only if the candidate point is selected .

3.2.5. Algorithm design

In this paper, the linear weighting method is chosen, and then the multi-objective criterion function is transformed into a single-objective criterion function. In the process of selecting sites for urban emergency logistics distribution centers, the number of alternative distribution centers that meet the requirements of the Construction Standards for Disaster Relief Material Distribution Centers will not be large, making the solution of the model relatively easy. Therefore, this paper selects the enumeration method to solve the multi-objective model. For the convenience of calculation, the set is represented by variables, i.e., a matrix is defined as follows $B = (b_{ij})_{m \times n}$,

Which, $b_{ij} = \begin{cases} 1, & d_{ij} \le S \\ 0, & d_{ij} > S \end{cases}$, thus (9) becomes $a_{ij} \le \sum_{j=1}^{n} b_{ij} y_j, \forall i \in I$。

First, compute all feasible solutions of $Y = \{y_1, y_2, y_3, \cdots, y_n\}$ and write the set of feasible solutions as $\psi = \{Y_1, Y_2, Y_3, \cdots, Y_q\} (q \le C_n^p)$, which $Y_i = (0, \cdots, 1, \cdots, 0, \cdots)$, indicate ψ in the feasible solution. The set of selected points is $\phi_i = \{i_1, i_2, \cdots, i_p\}$, where i_1 denotes the first value of 1 in Y_i, the selected site is selected, and the number of selected sites is p。

Applying equations (1) (4) (6) above for each feasible solution $Y_i (i = 1,2,\cdots,q)$ in ψ, Calculate the value of the objective function z_1. and write down $z_{11}, z_{12}, z_{13}, \cdots, z_{1q}$, and write down $z_1^{\max} = \max(z_{11}, z_{12}, z_{13}, \cdots, z_{1q})$ in turn.

Similarly, apply equations (2) (4) (5) (7) above to obtain the value of z_2, and write down $z_{21}, z_{22}, z_{23}, \cdots, z_{2q}$ in turn, and write down $z_2^{\max} = \max(z_{21}, z_{22}, z_{23}, \cdots, z_{2q})$.And obtain the value of z_3, $z_{31}, z_{32}, z_{33}, \cdots, z_{3q}$, $z_3^{\max} = \max(z_{31}, z_{32}, z_{33}, \cdots, z_{3q})$。

The problem of multi-objective planning is transformed into a single-objective problem according to a weighted approach. For each feasible solution $Y_i (i = 1,2,\cdots,q)$ in ψ solve the following model:

$$\min z = \frac{h_1}{z_1^{\max}} \sum_{i=1}^{m} \sum_{j \in \phi} d_{ij} - \frac{h_3}{z_2^{\max}} \sum_{i=1}^{m} \sum_{j \in \phi} \omega_i a_i + \frac{h_2}{z_3^{\max}} \sum_{j \in \phi} \sum_{i=1}^{m} c_{ij} d_{ij} x_{ij} + \frac{h_2}{z_3^{\max}} \sum_{j \in \phi} (f_j + C_j) y_j \quad \sum_{j=1}^{n} x_{ij} \ge D_i (i = 1,2,3,\cdots,m; j = 1,2,3,\cdots,n) \qquad (5)$$

$$x_{ij} \ge 0 (i = 1,2,3,\cdots,m; j = 1,2,3,\cdots,n) \qquad (7)$$

$$0 < h_1, h_2, h_3 < 1 且 h_1 + h_2 + h_3 = 1$$

The final value of z, denoted as $z_1, z_2, z_3, \cdots, z_q$, $z^* = \min\{z_1, z_2, z_3, \cdots, z_q\}$ is obtained, which in turn leads to the optimal solution a for z, the optimal transport volume $\{x^*_{ij}\}$, the most selected site Y^*, and the set of selected sites ϕ^*.

4. Case Study - Beijing as an example

4.1. Data Acquisition

Taking into account the actual situation in Beijing, this paper has selected one alternative site in each of the east-west and north-south locations in Beijing, as shown in Table 2 below. The specific locations of these emergency logistics distribution centers are shown in the map below.

Table 2 Alternative locations for emergency logistics distribution centers

Initial alternative locations	Features
j=1	Located in Tongzhou District, which is a sub-center of Beijing, it is necessary to build an emergency logistics distribution center, located near National Highway 102 and assisted by another subway.
j=2	Located in Daxing District, it is chosen near Daxing Airport and has convenient transportation.
j=3	Located in Shijingshan District, unlike other alternative sites chosen in suburban districts and counties, j3 belongs to the urban area and can quickly support the central city, and its close proximity to the Shijingshan District People's Government enables a quick response.
j=4	Located in Changping District, it is close to the place where forest fires have occurred in recent years, and its site is adjacent to the university, which can protect students and teachers at school in the first place if danger occurs.

Figure 2 Emergency logistics distribution center alternative site specific location map

r_i is the probability of occurrence of emergencies in region I, q_i is the number of historical disaster incidents counted in region i, The probability of occurrence of emergencies is obtained by $r_i = \frac{q_i}{\sum_{i=1}^{i=16} q_i} (i \in 1,2,3,\cdots,16)$,and then the importance of each region is calculated according to $\omega_i = r_i \times (e_i + m_i)$, The importance of each region is calculated based on the probability of occurrence of emergencies, as shown in Table 3 below. To facilitate the study, this paper takes the government of each region as the emergency material demand point of the region. Let the set of emergency material demand points be $I = i_1, i_2, i_3, \cdots, i_{16}$,representing each of the 16 municipal districts. The distances between the site selection points and the demand points are shown in Table 4. The demand for emergency supplies at the demand point is estimated by the importance of the demand for each zone calculated above, and the specific demand for each zone is shown in Table 5 below. The transportation cost between the site selection point and the demand point is calculated according to the defined formula $C = c_{ij} \times d_{ij} \times x_{ij}$. Since the model assumes that only one type of emergency supplies are stocked, set $c_{ij} = 1$ for simplicity of calculation, and the results obtained are shown in Table 6. According to the relevant provisions in the Chinese national standards, the construction scale of disaster relief emergency logistics distribution center is 21,800 to 25,700 square meters for 720,000 to 860,000 people and 16,700 to 19,800 square meters for 540,000 to 650,000 people respectively, so the

construction area of j1, j2 and j4 are all 25,700 square meters and the construction area of j3 is 19,800 square meters. Then the construction cost and operation cost of distribution center are estimated by the scale of distribution center and total construction area, and the calculation results are shown in Table 7 below.

Table 3 Basic data statistics by district

No.	City Name	Total population m_i (million people)	Gross production value e_i (billion yuan)	Number of disaster accidents q_i	Probability of emergencies r_i	Regional importance ω_i
1	Dongcheng District	79.4	2910.4	10	0.031	92.850
2	Xicheng District	113.7	5007.3	39	0.121	620.245
3	Haidian District	323.7	7926	53	0.165	1357.870
4	Chaoyang District	347.3	6500	58	0.180	1233.365
5	Fengtai District	202.5	1829.6	27	0.084	170.393
6	Shijingshan District	57	630	15	0.047	32.003
7	Tongzhou District	167.5	1059.2	19	0.059	72.383
8	Mentougou District	33.1	249.3	3	0.009	2.631
9	Daxing District	171.2	2840.4	37	0.115	346.053
10	Fangshan District	125.5	810.9	15	0.047	43.621
11	Shunyi District	122.8	1992.9	10	0.031	65.705
12	Changping District	216.6	1071.8	19	0.059	76.024
13	Huairou District	42.2	328	8	0.025	9.198
14	Miyun District	50.3	340.93	5	0.016	6.075
15	Pinggu District	46.2	293.49	1	0.003	1.055
16	Yanqing District	35.7	195.29	3	0.009	2.152

Table 4 Distance between alternative points and demand points

Distance (km)	J=1	J=2	J=3	J=4
i=1	26.7	42.7	17.4	40.4
i=2	30.8	41.5	13.1	39.7
i=3	37.0	47.2	9.3	32.3
i=4	24.4	42.3	19.6	41.6
i=5	37.0	37.1	8.3	42.8
i=6	42.8	43.7	0.7	37.1
i=7	0.7	48.9	43.3	58.9
i=8	55.0	51.8	10.4	33.6
i=9	39.8	21.2	22.8	58.6
i=10	53.5	32.7	18.6	54.4
i=11	25.8	70.1	46.4	42.6
i=12	53.6	77.0	34.7	5.1
i=13	44.5	87.4	57.6	39.9
i=14	51.3	99.0	74.8	58.7
i=15	41.6	98.5	75.2	59.1
i=16	87.1	108.4	65.0	29.9

Table 5 Demand for emergency supplies at each demand point

	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9	i=10	i=11	i=12	i=13	i=14	i=15	i=16
D_i	93	621	1358	1234	171	33	73	3	347	44	66	77	10	7	2	3

Table 6 Transportation costs between alternative site locations and demand points

Distance (km)	J=1	J=2	J=3	J=4
i=1	2483.1	3971.1	1618.2	3757.2
i=2	19126.8	25771.5	8135.1	24653.7
i=3	50246	64097.6	12629.4	43863.4
i=4	30109.6	52198.2	24186.4	51334.4
i=5	6327	6344.1	1419.3	7318.8
i=6	1412.4	1442.1	23.1	1224.3
i=7	51.1	3569.7	3160.9	4299.7
i=8	165	155.4	31.2	100.8
i=9	13810.6	7356.4	7911.6	20334.2
i=10	2354	1438.8	818.4	2393.6
i=11	1702.8	4626.6	3062.4	2811.6
i=12	4127.2	5929	2671.9	392.7
i=13	445	874	576	399
i=14	359.1	693	523.6	410.9
i=15	83.2	197	150.4	118.2
i=16	261.3	325.2	195	89.7
总计	133064.2	178989.7	67112.9	163502.2

Table 7 Costs of the candidate emergency stockpile

Cost (million yuan)	J=1	J=2	J=3	J=4
Alternative point	133064.2	133064.2	67112.9	163502.2
Transportation Costs	132.6	132.6	102.2	132.6
Operation Cost	1591.3	1591.3	1226.0	1591.3
Construction Cost	134788.1	134791.1	134794.1	134797.1

4.2. Model Calculation

Substituting the above data into the nominal model consisting of equations (1) to (9), assuming the maximum service distance of the given emergency reserve , the calculation results are obtained as shown in Table 8. According to the calculation results in Table 8, the Beijing emergency logistics distribution center should be built at the alternative site j_2 .

Table 8 Calculation results

Quality grade	Z1	Z2	Z3	Z
J=1	100.9	23333.8	4020	27454.7
J=2	163.6	115855.7	2743	118762.3
J=3	185.2	530779.0	4890	535854
J=4	440.2	253638.5	773	254851.7

Table 4-2 Curves of the different finger database

Algorithm	90		95	
	Different values	Refers to the order	Different values	Refers to the order
In this paper	8.3	7.5	20	17.4
Average cycle fingerprint classification	17.4	10.1	25.3	22.3
Singularity fingerprint retrieval	26.8	20.2	30.7	19.3

5. Conclusion

This paper studies the emergency logistics site selection problem, delves into the micro level, takes the maximum coverage demand, the minimum total distance and the lowest total cost and expense as the micro site selection objectives, establishes a multi-objective mathematical planning model, and designs an algorithm for solving the model based on its characteristics and practical needs, and then puts the model into a case study. It provides a new practical method for emergency logistics site selection decision and valuable experience for the construction of emergency logistics distribution centers in other regions.

Therefore, basic detail method has more technical accumulation in low quality fingerprint image processing ability.

It can be seen that compared with the traditional retrieval algorithm based on geometric features between detail points, the retrieval algorithm adopted in this paper not only has a significant improvement in system retrieval ability, but also has the best stability performance under different fingerprint databases.

Based on the above reasons, this paper chooses the basic research direction, detail-based fingerprint index and retrieval method, and builds the index structure and retrieval method of large-scale fingerprint database.

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